Gary Kleppel[1], Enrique Manzanilla[2],
B. Teter[3] and S. Petrich[4]

SANTA MONICA BAY PLANKTON DISTRIBUTION

Phytoplankton can be used as indicator organisms in estuaries where they show the extent and results of eutrophication and contamination (Malone 1977; Kleppel and McLaughlin 1980), but they are less definitive in open coastal waters (Eppley *et al.* 1972; Thomas in SCCWRP 1973).

In January 1980, we began a series of cruises in Santa Monica Bay, to determine if phytoplankton abundance and composition, in the vicinity of the Hyperion 5-mile outfall, differed from that along an onshore-offshore transect in the bay. Our objective was to ascertain whether or not plankton and nutrient distributions were influenced by waste water discharge.

The results suggest that a multiplicity of nitrogen sources drive phytoplankton growth and distribution in Santa Monica Bay. Topography and water circulation patterns in the bay seem to provide both the nutrients and the physical environment conducive to the enhancement of phytoplankton biomass relative to other parts of the Southern California Bight. We detected nothing unusual in net phytoplankton abundance, distribution, or composition in the vicinity of the outfall. We observed that zooplankton abundance at the outfall station was higher than elsewhere along the transect, but found it impossible to define the process (growth, entrainment, migration) responsible. Nonetheless, the existence of above normal numbers of zooplankton at this location suggests that these animals may have some contact with the wastefield.

METHODS

Nine stations (lines 2 and 3 - 7, Figure 1) were sampled at approximately monthly intervals from January 1980 to January 1981. Stations were selected to permit detection of onshore/offshore trends, encompass areas of waste water discharge, and coincide with line 300 of the Southern California Bight Studies (Eppley *et al.* 1978). The sampling program was designed to minimize the time spent on station. Samples were collected between 0800 and 1330 hours; the time on station was usually 8-12 minutes. No cruise was made in December 1980; in January 1981 heavy weather prevented sampling at stations 7C, 3C, and 3D.

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[1] Allan Hancock Foundation, University of Southern California, Los Angeles, CA 90089
[2] SCCWRP
[3] Department of Biology, California State University, Long Beach
[4] Hyperion Treatment Plant, Playa Del Rey, CA

At each station the euphotic zone (depth to 1% incident light penetration: 1% I_0) was estimated as times the secchi depth, and a submersible pump was lowered through the euphotic zone (or to a depth of 60 to 100 m on cruises from August 1980 to January 1981). The water pumped from depth was collected in a large plastic container, mixed, and subsampled (1 liter) for net phytoplankton identification and enumeration (Palmer and Maloney 1954 method).

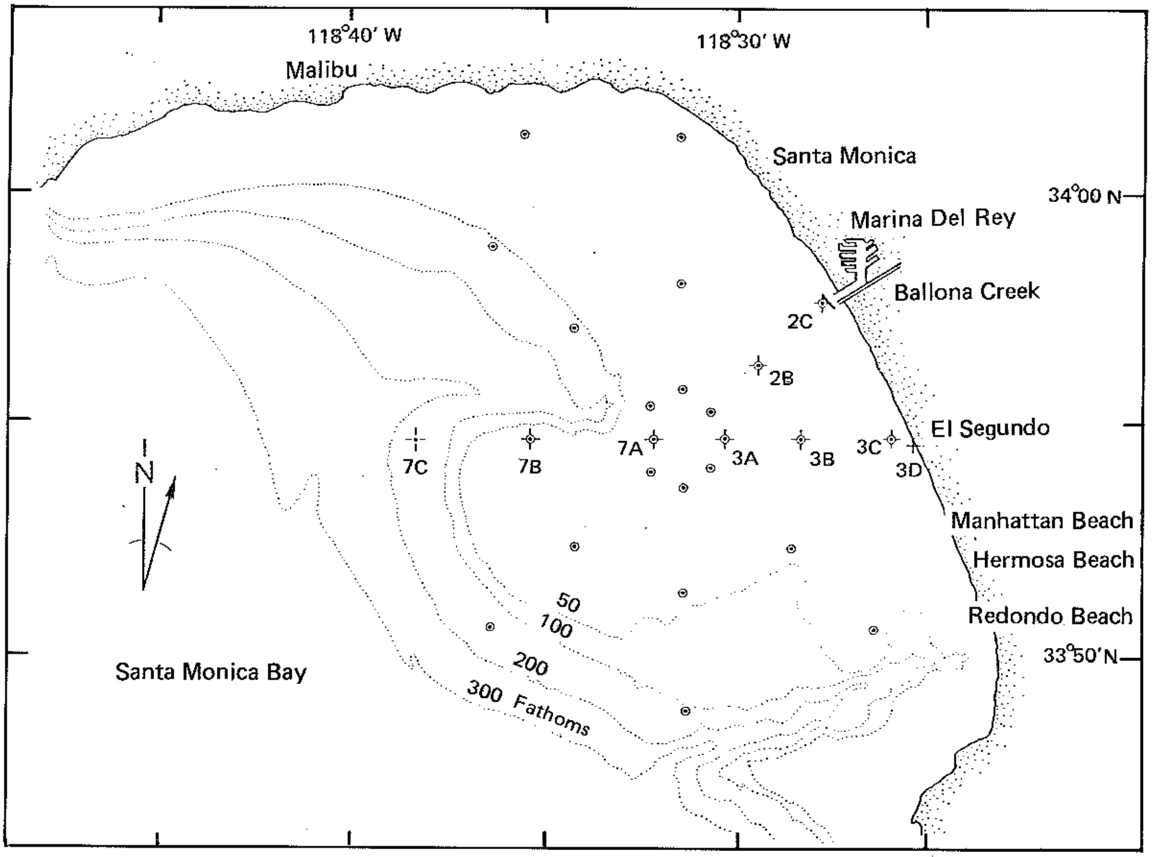


Figure 1. Station locations in Santa Monica Bay. Stations marked by crosses were sampled during the present study. Stations marked by dots were sampled by Los Angeles City from 1957-1970; stations marked by open circles have been sampled from 1957-present.

Additional samples were taken at the 10% light penetration (10% I_0) depth and sometimes at the fluorescence maximum depth (see below). As the pump was raised, samples for ammonium (Solorzano 1969), nitrate + nitrite determination (Strickland and Parsons 1972) and chlorophyll *a* calibration (Strickland and Parsons 1972) were collected at the 1% and 10% I_0 depths and at 5 and 0.5 m from the surface. A continuous temperature profile was made at each station using a 60-m bathythermograph.

Beginning in February 1980, a Turner Designs model 10 fluorometer was connected to the hose such that water pumped to the surface passed through the fluorometer as the pump was being lowered, providing a continuous profile of chlorophyll fluorescence. The water was then passed to the container for phytoplankton sampling. A malfunction in the fluorometer prevented profiling on the July 1980 cruise.

Beginning in March 1980, a CalCOFI vertical tow (CalVet) net was used to sample zooplankton at each station along the transect. The net, (mouth diameter 25 cm; mesh size 335 um) rigged to sample only as it is raised, was lowered to 70-m or near bottom, remained there for 10 s, then was raised at an average speed of 0.6 $m \cdot s^{-1}$. Samples were preserved in 10% formalin and returned to the laboratory for determination of settled volume and sorting.

RESULTS

Infra-red imagery from the NOAA-6 satellite radiometer was used to obtain synoptic information on surface temperature distributions, and to indicate surface circulation patterns in the Bay. Imagery from 10 July and 24 September 1980 (Figure 2), representative of patterns observed from spring to fall, suggest cool water (lighter shades) advection into the bay from sources in the Santa Barbara Channel, and warm water input from downcoast.

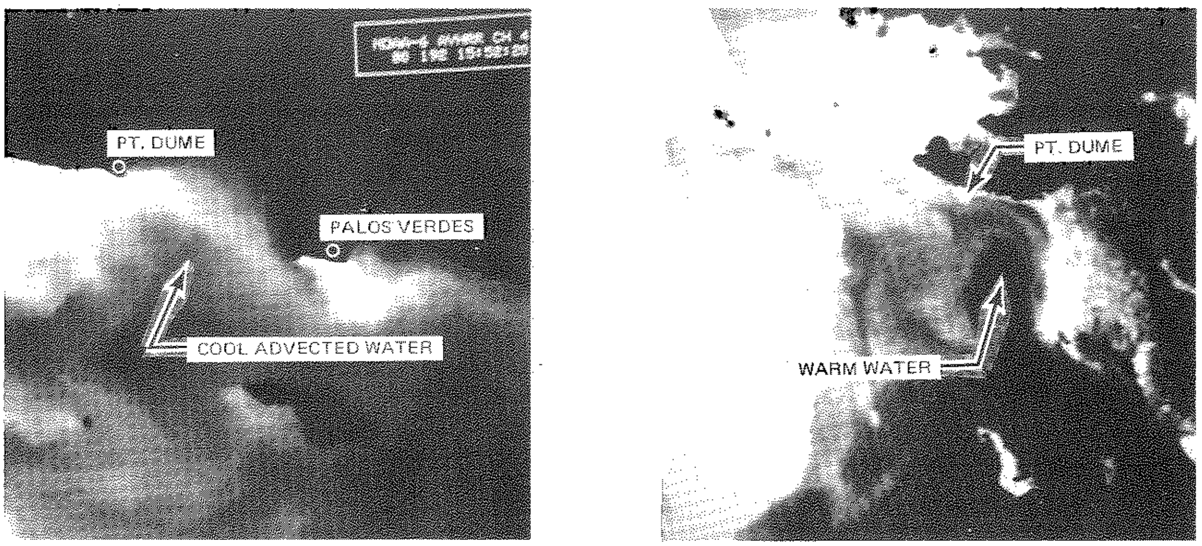


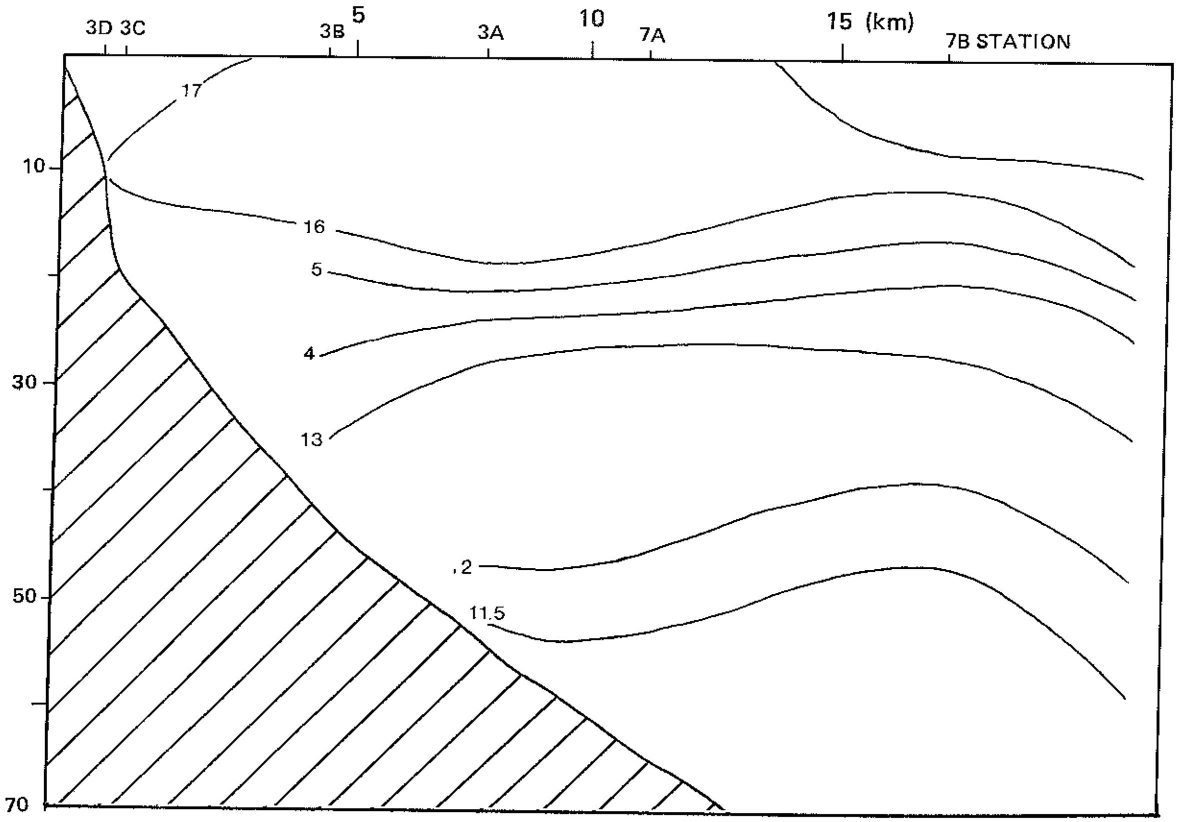
Figure 2. NOAA-6 satellite radiometer (AVHRR) thermal infra-red images of relative sea surface temperature, from 10 July (left) and 29 September (right) 1980. Shades of grey from dark to light are from warm to cold.

Apparently, transport of upwelled and California Current water from the channel during spring and summer results in the depression of surface temperature along an upcoast to downcoast plume across the bay. Similar features have been observed in succeeding years. During late summer and fall, cooler water is entrained along shore by advection of warmer water from downcoast.

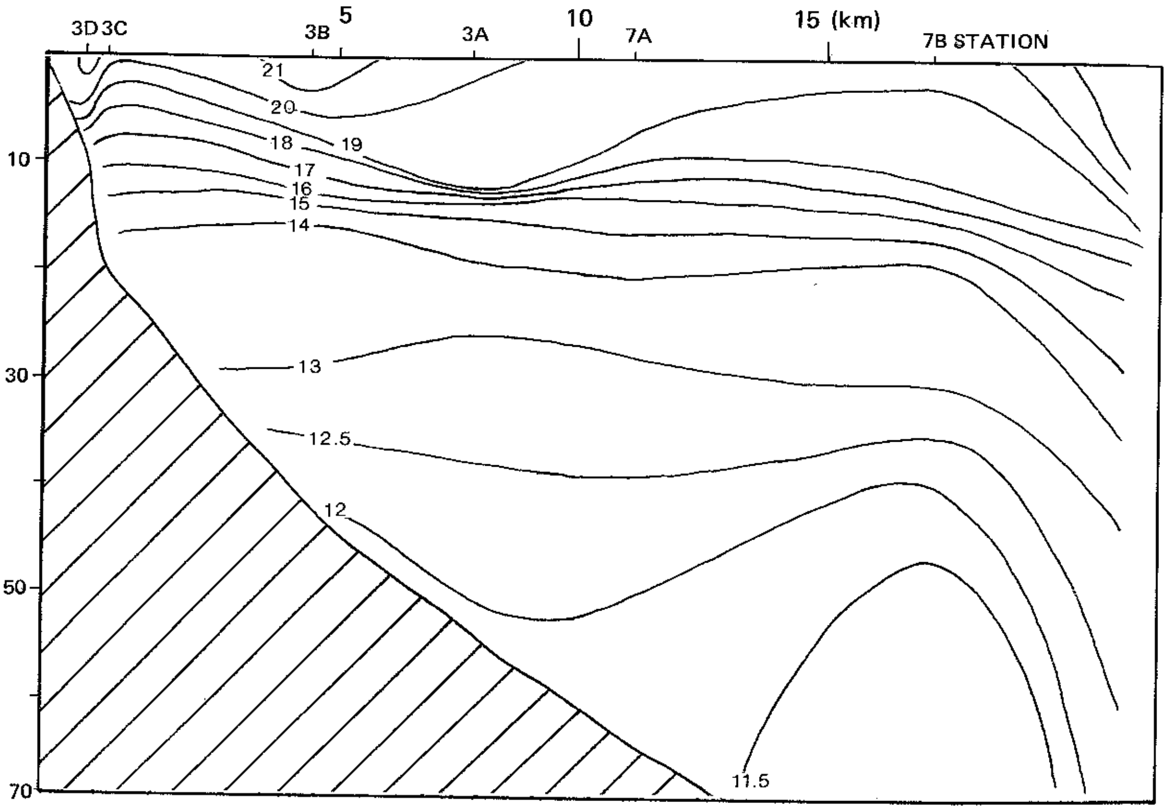
Vertical temperature gradients along the transect occurred between 10 and 20 meters. About 75% of the time, these gradients were less than 0.3° $\cdot m^{-1}$ at their steepest point. During late summer to early fall, thermal gradients were steeper (0.5-0.7° $\cdot m^{-1}$) and somewhat shallower (10 m). Evidence of the surface, cool-water feature described above was seen in several months as a depression of surface temperature of a few tenths to several degrees near the middle of the transect (Figure 3).

INORGANIC NITROGEN DISTRIBUTIONS

Nitrate enters the euphotic zone in Santa Monica Bay by vertical diffusion (Eppley 1979a). The nitrocline sharp increase in nitrate concentration) depth is linearly related ($r^2 = 0.94$; p 0.001) to the depth of 1% incident light penetration. However, the presence of near surface nitrate-N concentrations between 0.1 and 3.0 ug-at/liter suggests that horizontal advection of nitrate in water masses derived from Santa Barbara Channel (Figure 4a-b) may also be an important source of nitrogen to the bay.



TEMPERATURE (°C) CRUISE 80.05.08



TEMPERATURE (°C) CRUISE 80.08.29

Figure 3. **a) Isotherms for lines 3 and 7 on 8 May (cruise 80.05.08) and b) 29 August 1980 (cruise 80.08.29).**

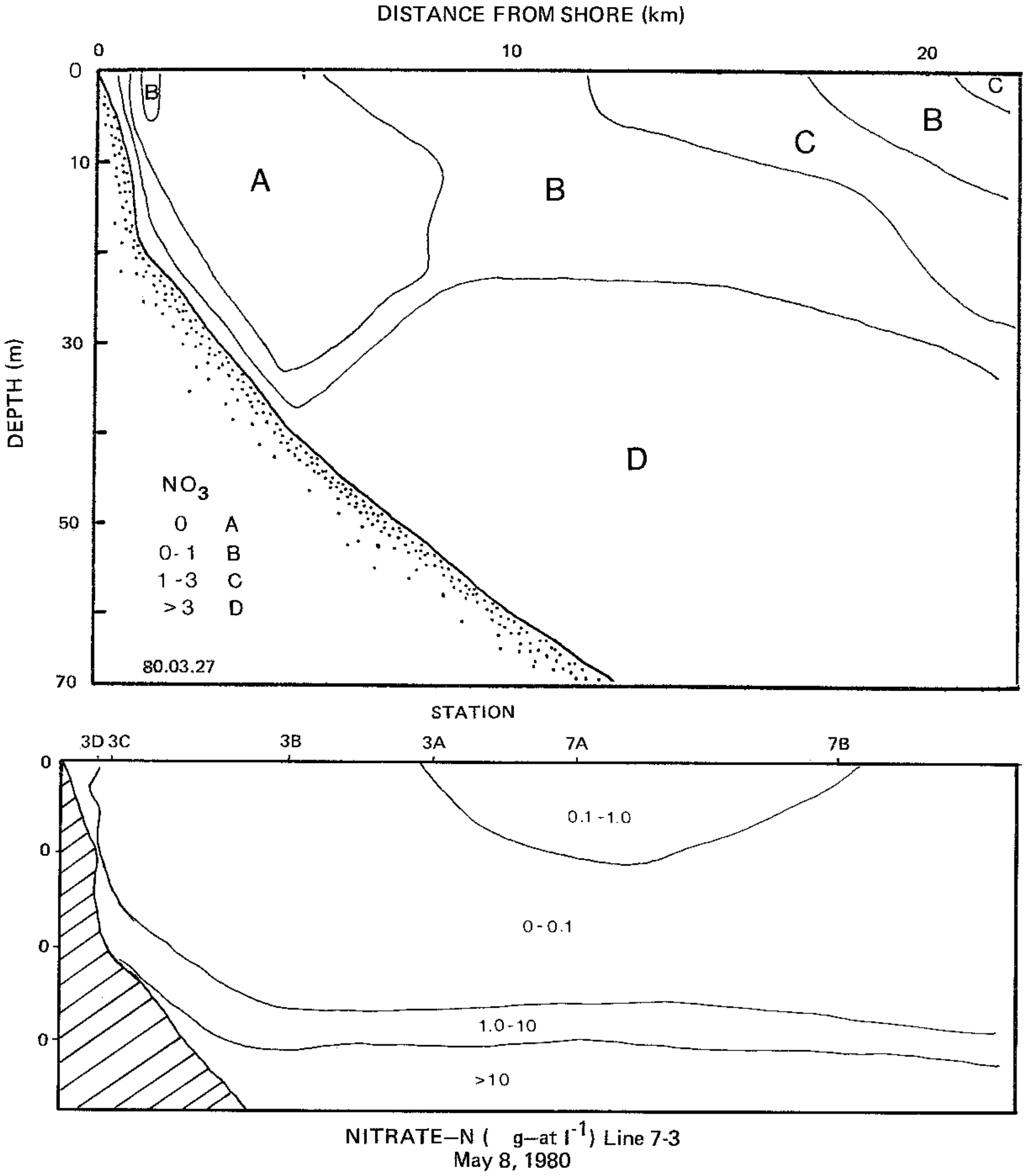


Figure 4. Concentrations of nitrate-N for a) 27 March 1980 and b) 8 May 1980 along lines 3 and 7, illustrating the advective input of nitrate to surface waters.

The presence of ammonium is indicative of regenerated, or sewage nitrogen (a form of "new" nitrogen), or runoff. During a storm on 27 March (Figure 5a), a surface lens of >3 ug-at/liter of NH_4 -N extending about 5 km from shore was suggestive of coastal runoff. A second plume, at 5-20 meters in the vicinity of the 1-mile Hyperion outfall, was due to the discharge of stormwater overflow from the treatment plant (J. Nagano pers. comm.). Frequent observations of NH_4-N concentrations of 2-5 ug-at/liter near the bottom between stations 3C and 3B (Figure 5 b-c) suggest that the periodic flushing of the 1-mile HTP outfall, rather than the Chevron Oil

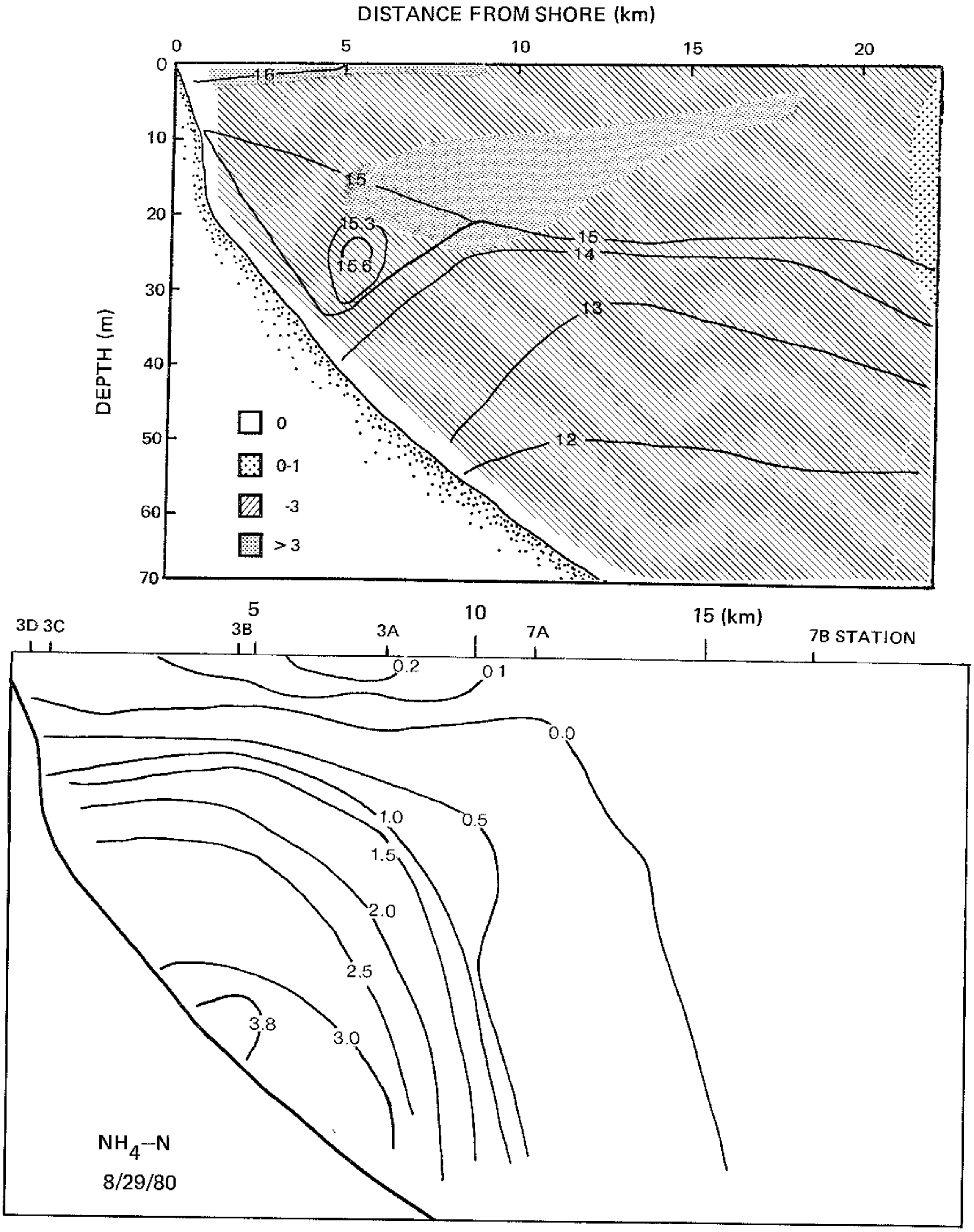
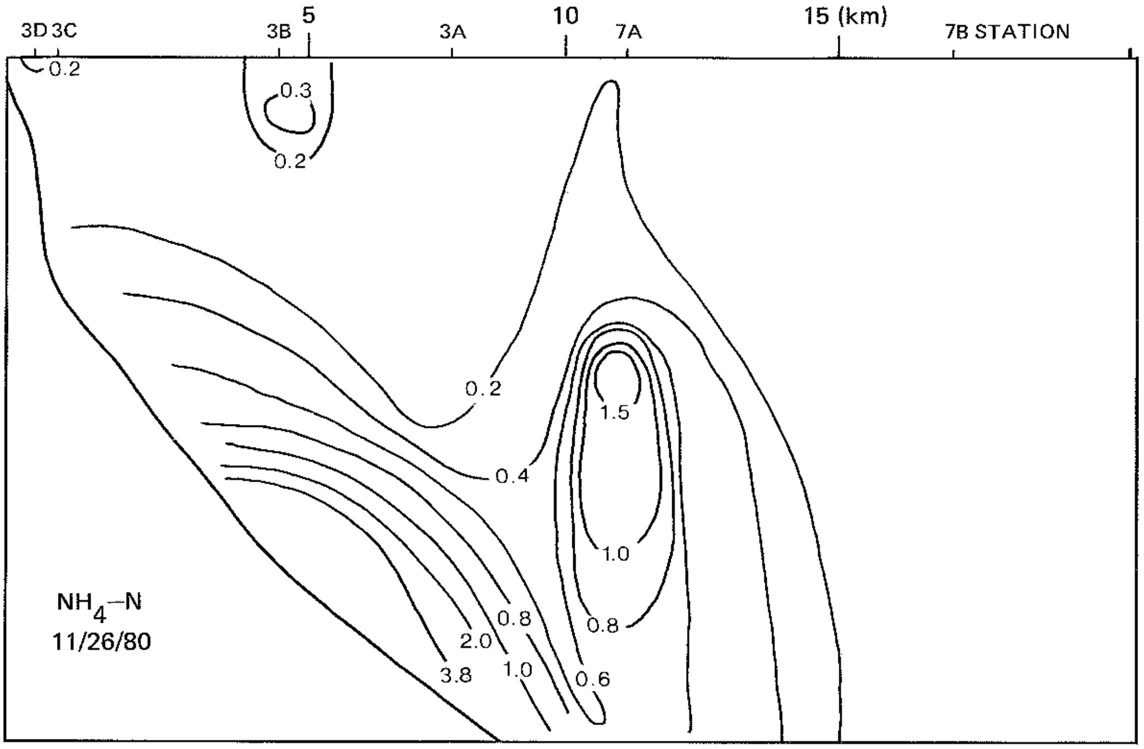
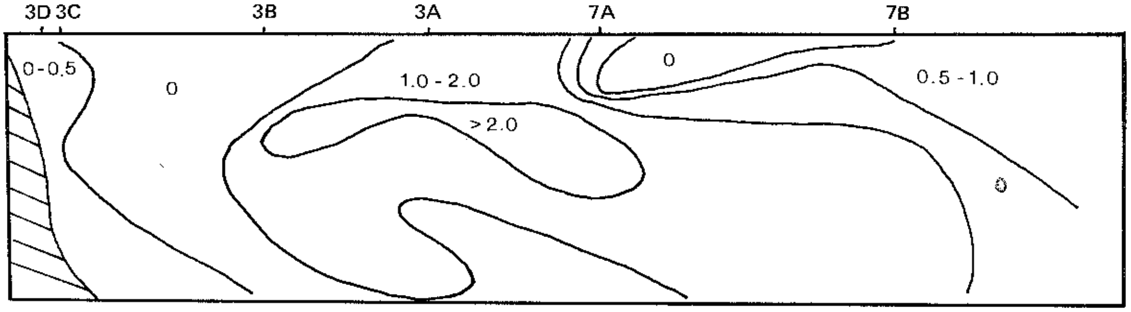


Figure 5. Concentrations of ammonium– N (μg-at/1) in Santa Monica Bay in 1980 showing a) storm water runoff (29 March; isotherms superimposed); b) near-bottom increase around station 3B (29 August); c) near-bottom peak and midwater peak (26 November); d) midwater peak (8 August).





AMMONIUM–N (μg–at l^{-1}) Line 7-3
August 8, 1980

Co. outfall plume (Eppley 1979b), provides a consistent ammonium signal nearshore. We observed ammonium values between 2 and 3 ug-at/liter near the Chevron outfall during winter, but not during the summer when the discharge frequently occurs above the 1% I_0 depth.

Nitrogen discharged from the 5-mile Hyperion outfall was rarely detectable in the euphotic zone. However, during late summer and fall, increased ammonium concentrations were observed at mid-water column depths along the central part of the transect (stations 3B, 3A and 7A) often in contact with the thermal gradient (Figure 5d). The most apparent explanation for these peaks is nutrient regeneration. However, it is also possible that they represent an accumulation of wastefield ammonium along a density interface (thermocline).

PHYTOPLANKTON DISTRIBUTION

Well developed chlorophyll-fluorescence maxima were observed at stations 1-22 km from shore in about 78% of our profiles. The average fluorescence maximum depth (midpoint of the peak) was within 6 meters of the thermocline, and for all data the average fluorescence maximum depth (17.3 m) was 3 meters below the center of the average thermal gradient depth (14.3 m). However, a significant relationship between the fluorescence maximum and thermocline depths occurred only when the strength of the thermal gradient was between 0.5 and 0.69° · m^{-1} (Table I).

More consistent relationships were detected when fluorescence maximum depth was regressed against secchi ($r^2 = 0.74$) and nitricline depths ($r^2 = 0.67$). Net-phytoplankton composition in Santa Monica Bay is typical of other areas of the Bight. During 1980, a *Gymnodinium splendens* bloom occurred in March and persisted along the southern California coast through July. In late July, *G. splendens* was succeeded by a bloom of *Gymnodinium flavum*, which formed cell maxima at 10-20 meters (Dmohowski *et al.* 1980). In late August to September two green algal blooms occurred--*Staurastrum* sp. (August) and *Halosphaera* sp. (September). Figure 6 a-b shows the onshore/offshore distributions of diatoms and dinoflagellates over the study period. Temporal fluctuations in onshore/offshore diatom abundance decreased with shoreward distance. Average phytophankton abundances were on the order of 40-60 cells · ml^{-1}. We found no evidence that the phytoplankton assemblage at station 7A (the outfall location) was consistently different in numbers, composition, or expected time series trends from the phytoplankton assemblage elsewhere along the transect.

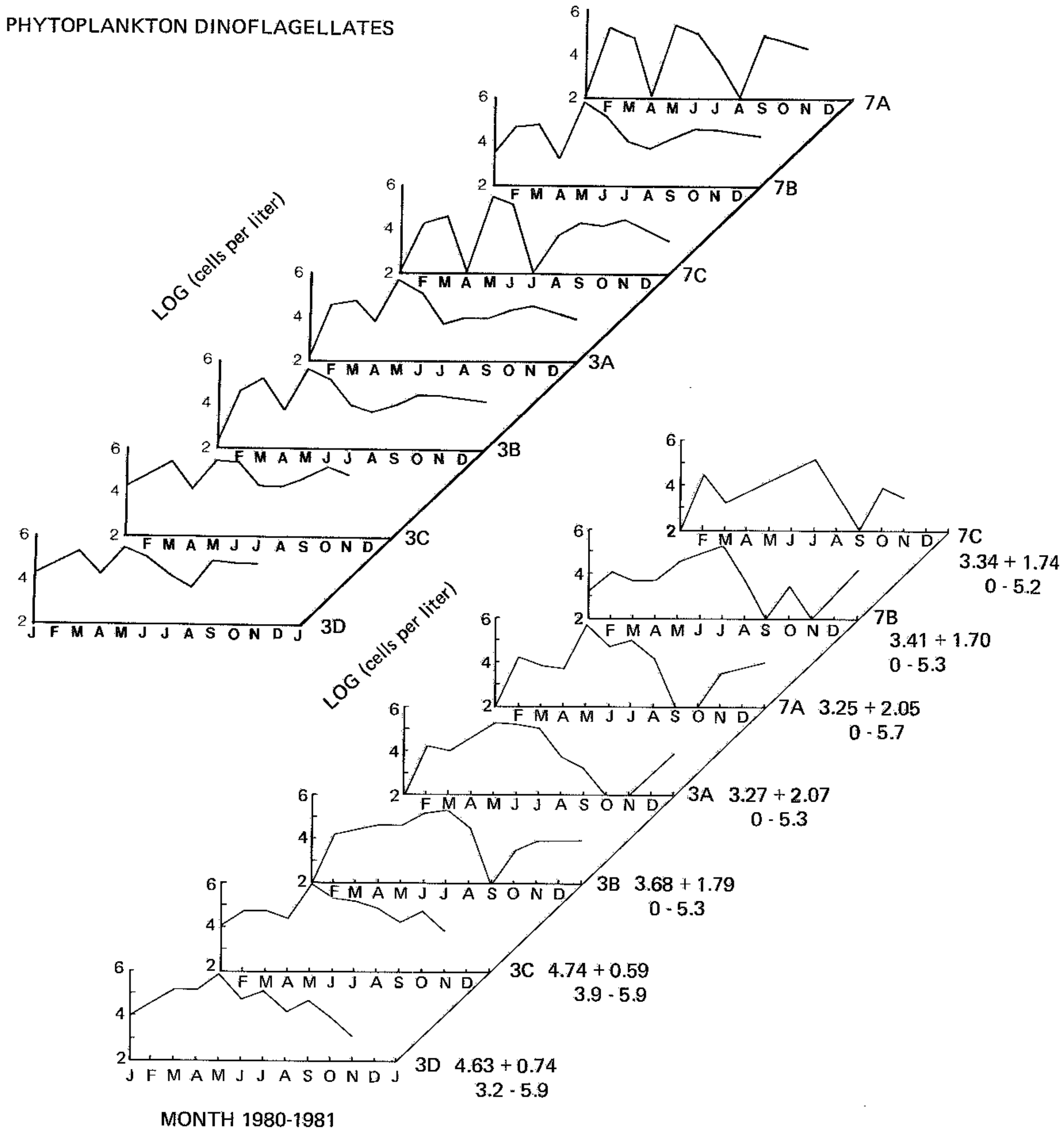
We examined a portion of the time series collected by Hyperion personnel over a fourteen year period (1957-1970) to evaluate the possibility that phytoplankton blooms occur some distance from the outfall. Some examples of these data are shown in Figure 7. They suggest a low level enhancement in phytoplankton abundance at various locations in the bay. The locations where the highest phytoplankton abundances occurred are often regions influenced by water advected from the Santa Barbara Channel, as well as being near the site of waste discharge. We conclude, therefore, that the circulation patterns described by Hendricks (1980) and suggested by satellite imagery, along with a multiplicity of nutrient sources, apparently gives rise to a fertile region for phytoplankton growth. It is impossible at this point to detect any effect on the phytoplankton caused by the 5-mile Hyperion wastewater discharge.

ZOOPLANKTON DISTRIBUTIONS

Figure 8 is a plot of zooplankton distributions along line 7-3 for July 1980. This is representative of the pattern observed on many cruises. Further analysis indicated that nearshore, the zooplankton were dominated by *Acartia tonsa*. *Calanus pacificus* became dominant about 5-km from shore. These distribution patterns are typical of coastal regions. Most significant in

Table 1. Relationships between chlorophyll fluorescence maximum depth and the depth of the midpoint of the vertical thermal gradient at various intensities in Santa Monica Bay for 1980.

	Thermal Gradient Intensity (degrees per meter)				
	0.1-0.29	**0.30-0.49**	**0.50-0.69**	**≥0.7**	**All Data**
Number of cases	28	18	9	8	69
Mean fluorescence maximum depth (m)	16.2	13.8	20.8	18.2	17.3
Mean depth of thermal gradient (m)	20.0	13.4	14.5	9.2	14.3
Correlation (r^2)	0.46	0.46	0.64	0.04	0.42
Probability	<0.001	<0.01	<0.01	<0.05	<0.01



PHYTOPLANKTON DINOFLAGELLATES

Figure 6. Log numbers of a) diatoms and b) dinoflagellates per liter at each station on each cruise.

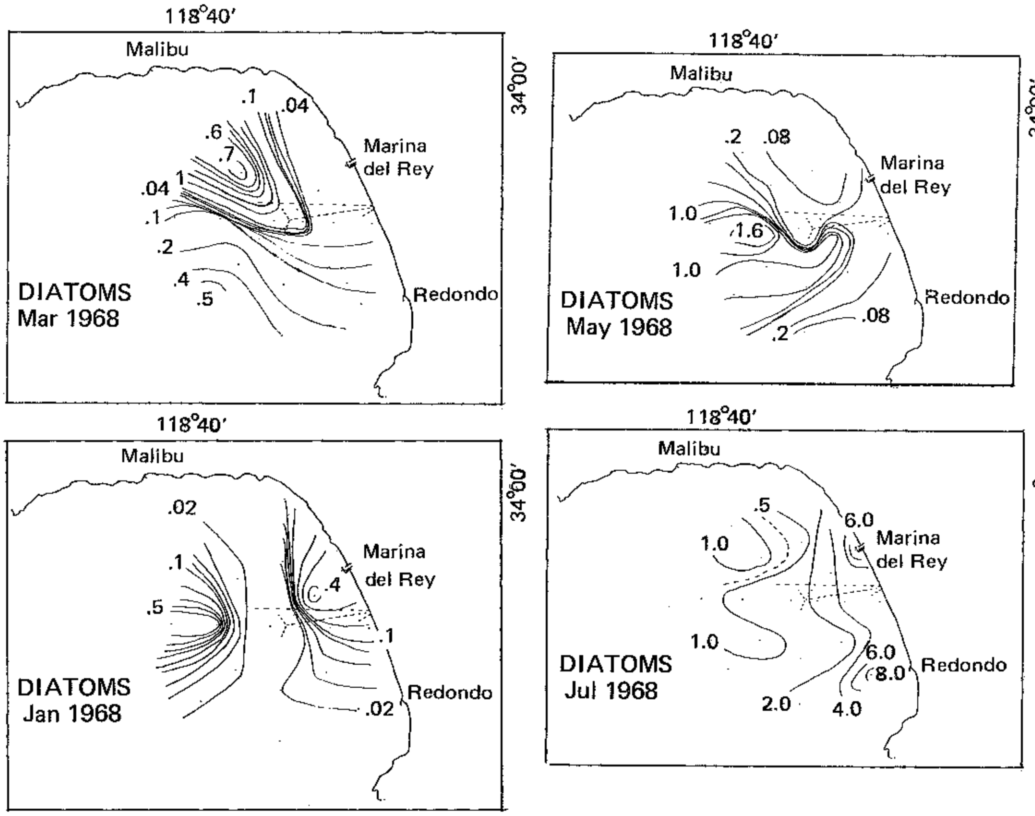


Figure 7. Relative abundances of diatoms in the HTP-survey area in representative months in 1968 (a typical year).

Figure 8 is the peak in abundance (of *Calanus*) at station 7A, the 5-mile Hyperion outfall station. Settled volumes were generally higher at station 7A than elsewhere. Regression of zooplankton volume on log phytoplankton density (Figure 9a) along line 7 explained 74% ($p < 0.01$) of the variance in either parameter suggesting the co-occurrence of phytoplankton and zooplankton standing stocks expected in natural systems. However, when lines are fitted by inspection through the data points for each station, there is a trend toward increasing slope with shoreward distance (Figure 9b). It would appear that at stations along line 7, the same number of phytoplankton were associated with different zooplankton abundances. Several interpretations of this observation are possible; these are discussed more fully below. We note here that one explanation is that a supplemental source of food, possibly detrital material or increased phytoplankton biomass (which is grazed off, and hence not seen) is provided in this region.

DISCUSSION

Although phytoplankton standing stocks in Santa Monica Bay tend to be higher than average in the Southern California Bight (Eppley *et al.* 1978), the composition of the net-phytoplankton seems fairly typical. There were no blooms of "so-called" nuisance species, such as recurring or persistent red-tides, in any one place along our transect.

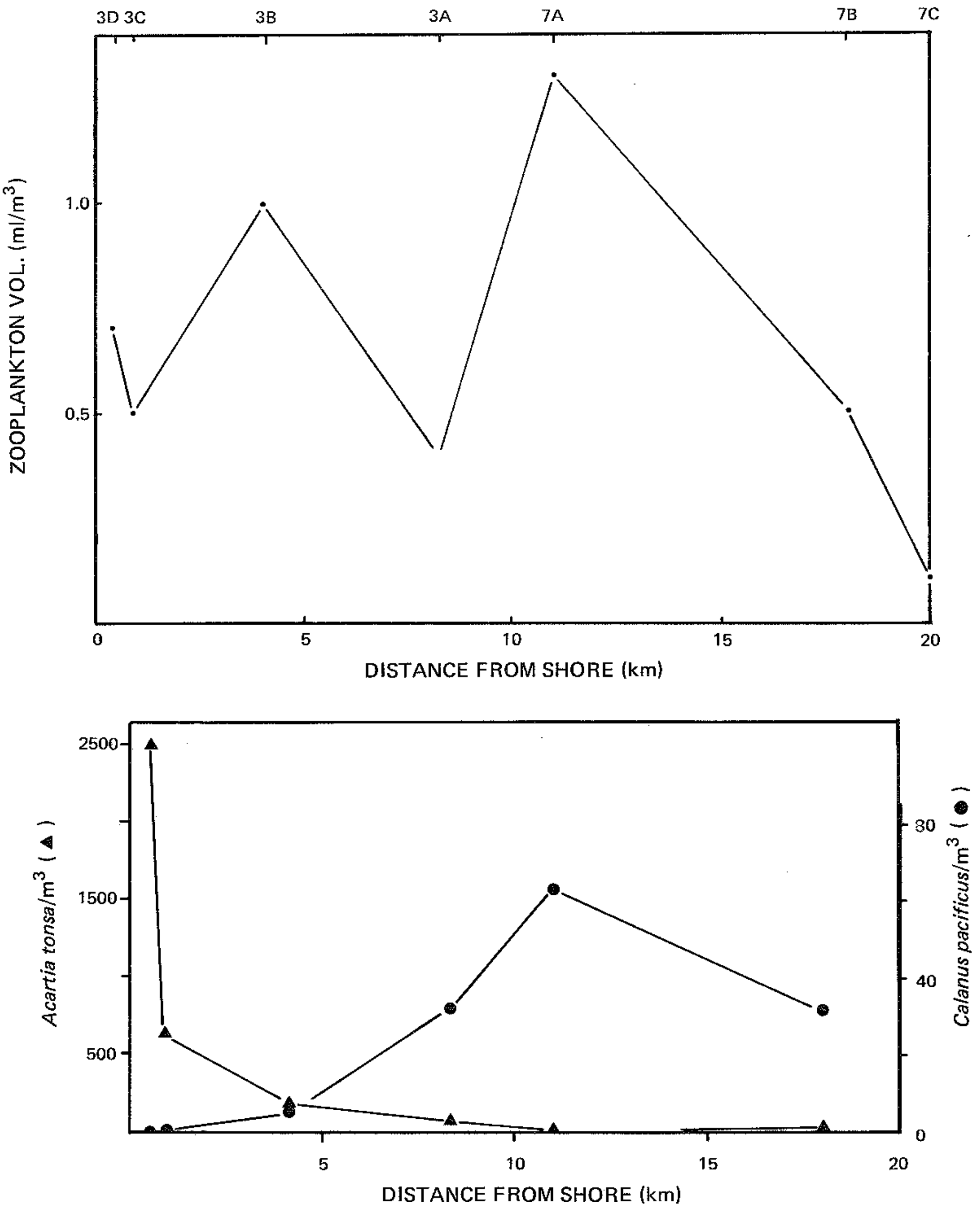


Figure 8. a) Zooplankton settled volumes for lines 3 and 7 on 10 July 1980, showing trends in abundance reflective of the entire study. b) Distributions of the two dominant copepod species in CalVet tows during 1980, along lines 3 and 7. Data are for 29 September.

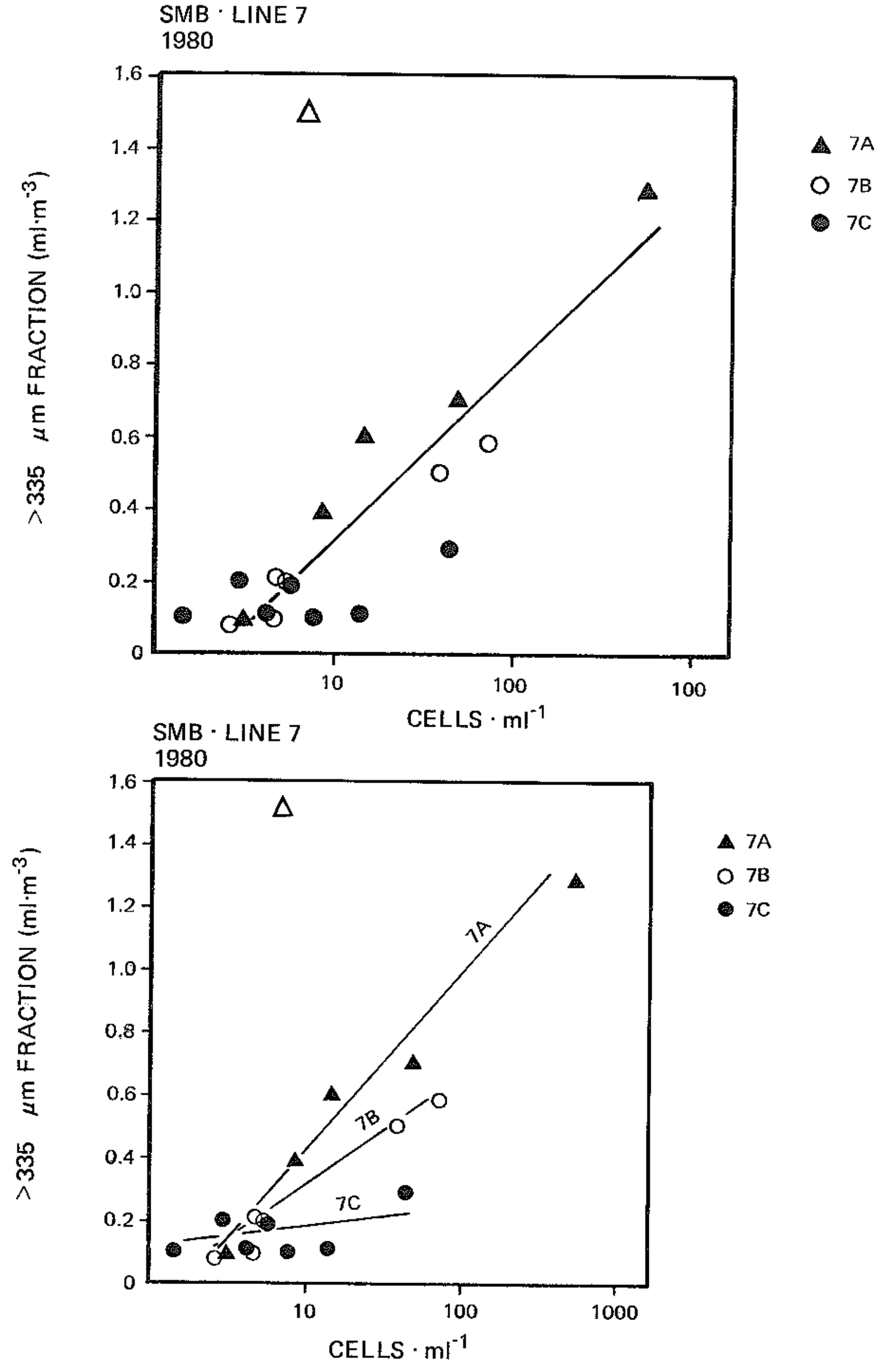


Figure 9. Regression of zooplankton settled volume (>335 μm fraction) on phytoplankton density for line 7. Open triangle is for station 7A in May, which was dominated by fish eggs and larvae. This point was not used in computation of the regression. a) All line 7 stations together ($r^2 = 0.74$; p 0.01). b) Each line 7 station individually (lines fit by inspection).

It can be argued that such blooms would not be expected close to the Hyperion 5-mile outfall (station 7A), but rather, several kilometers downstream. However, Eppley *et al.* (1972) reported a significant increase in chlorophyll fluorescence and ATP in the vicinity of the White Point outfalls. Further, Hendricks (1980) suggested the existence of a subsurface eddy in Santa Monica Bay, and calculated the median water velocity to be lower than in other areas in the Bight where current meter measurements were made. The existence of an eddy in the bay is also suggested from surface temperature measurements made over nearly 20 years by the Los Angeles City and by recent satellite imagery. In one study (T. Hendricks, pers. comm.), drogues placed at depth above the 5-mile outfall remained in that area, moving in a wide circle, for about 2 days. Although this is an isolated case, it suggests that periodically, the wastefield may remain in the vicinity of the outfall for extended periods.

Concentrations of nitrate, ammonium, or both were frequently above zero in the euphotic zone indicating a higher rate of nitrogen supply than removal. In the winter and late summer, ammonium levels were elevated; in late winter-early summer, nitrate concentrations were above zero in many parts of the transect with peaks seaward of station 3A.

Not unexpectedly, nitrate and ammonium levels were usually higher near the bottom of the euphotic zone that at the surface, suggesting that light intensity may be important in regulating phytoplankton growth and hence DIN assimilation (also see Eppley *et al.* 1979b). The strong relationships between secchi depth, nitricline depth, and fluorescence maximum depth support this. Part of the variance in the relationship between nitrate concentration and light penetration is possibly explained by the advection of NO_3-N in water from the Santa Barbara Channel.

Nearshore, (lines 2 and 3), ammonium may be supplied by discharge from marinas, nearshore outfalls, and recycling by animals and bacteria. The mean ammonium concentration in the discharge from the Chevron outfall (near station 3D) diluted 75:100 times is 3.07-2.30 ug-at N/liter. During winter, the mean euphotic zone NH_4-N was most frequently on the order of 2.3 ug-at/liter. During the summer, however, NH_4-N levels were on the order of 0.14 ug-at/liter. Given a constant rate of discharge from the Chevron outfall, the low NH_4-N during summer may be indicative of increased assimilation of N by phytoplankton. The observednear-bottom elevation of ammonium in the region between stations 3C and 3B suggests of an ammonium source, which we believe to be discharge from the 1-mile Hyperion outfall. Discharge of "new" nitrogen from the 1-mile and Chevron outfall may be important for stimulating growth in (Eppley *et al.* 1979b) nearshore phytoplankton shore stocks.

In waters seaward of these stations it becomes difficult to ascertain either the source or the significance of ammonium to the phytoplankton. Features such as midwater ammonium peaks may be due to nitrogen regeneration, (Figure 5d), accumulation of wastefield nutrients along physical gradients (Figure 5c), or the combination of both.

With seaward distance, ammonium becomes less important as a nitrogen source for phytoplankton growth in the upper euphotic zone, but remains the principal form of nitrogen assimilated below the 10% I_O depth (Eppley *et al.* 1979b). The mean depth of the 10% I_O level in the study area was 13.6 m. The mean depth of the fluorescence maximum layer was 17.3 (5% I_O). Overall, 51% of the fluorescence maxima occurred within the 1 and 9% incident light penetration depths, in good agreement with the findings of Cullen and Eppley (1981), and suggesting that ammonium may be an important nitrogen source to a large part of the phytoplankton standing stock.

The persistence of high zooplankton volumes at station 7A may be due to wastewater discharge. Several alternative hypotheses need to be tested regarding the cause of this peak. One hypothesis is that waste discharge causes an elevation in primary production which is grazed down by the zooplankton. A second is that the zooplankton feed on materials in the wastefield directly. Both of these are supported by the data in Figure 9b, suggesting a supplemental food source around station 7A. It is also possible that due to the circulation or topography of the region, zooplankton are simply entrained there. Further study of the elevation of zooplankton in the vicinity of an outfall may be appropriate.

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